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Grossman

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[54] **LED DRIVING CIRCUITRY WITH LIGHT INTENSITY FEEDBACK TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED**

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[73] Assignee: Dialight Corporation, Manasquan, N.J.

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[51] Int. Cl.^{7} G05F 1/00

[52] U.S. Cl. 315/291; 315/149; 315/150; 315/156

[58] Field of Search 315/291, 159, 315/149, 150, 156; 363/89; 359/189; 250/199, 214, 205, 201.5, 216, 271, 458.1

[56] **References Cited**

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5,608,225 3/1997 Kamimura et al. 250/458.1

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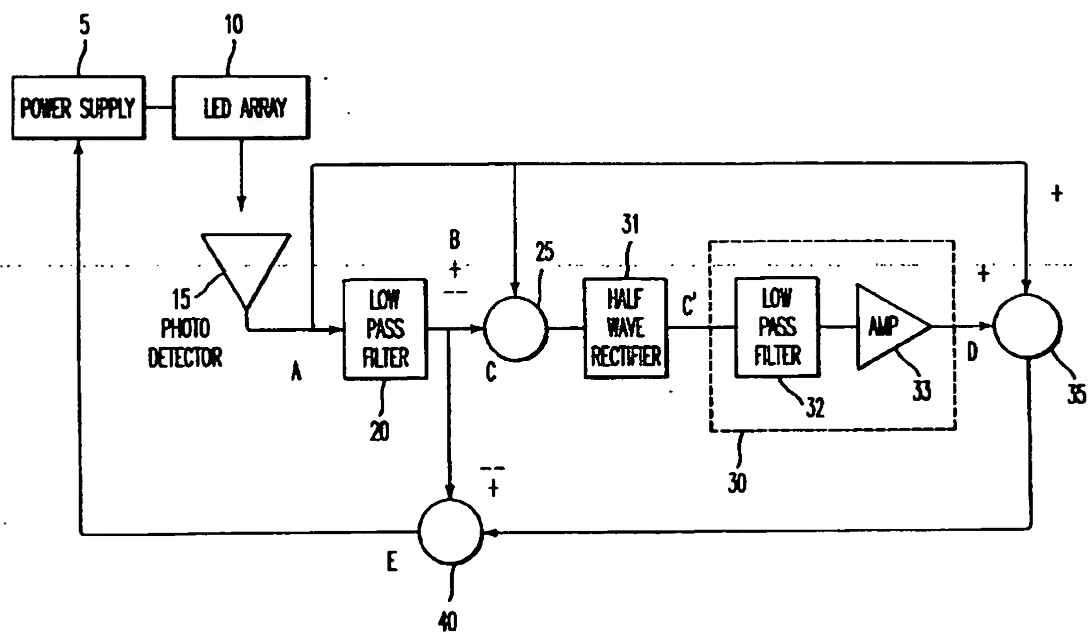
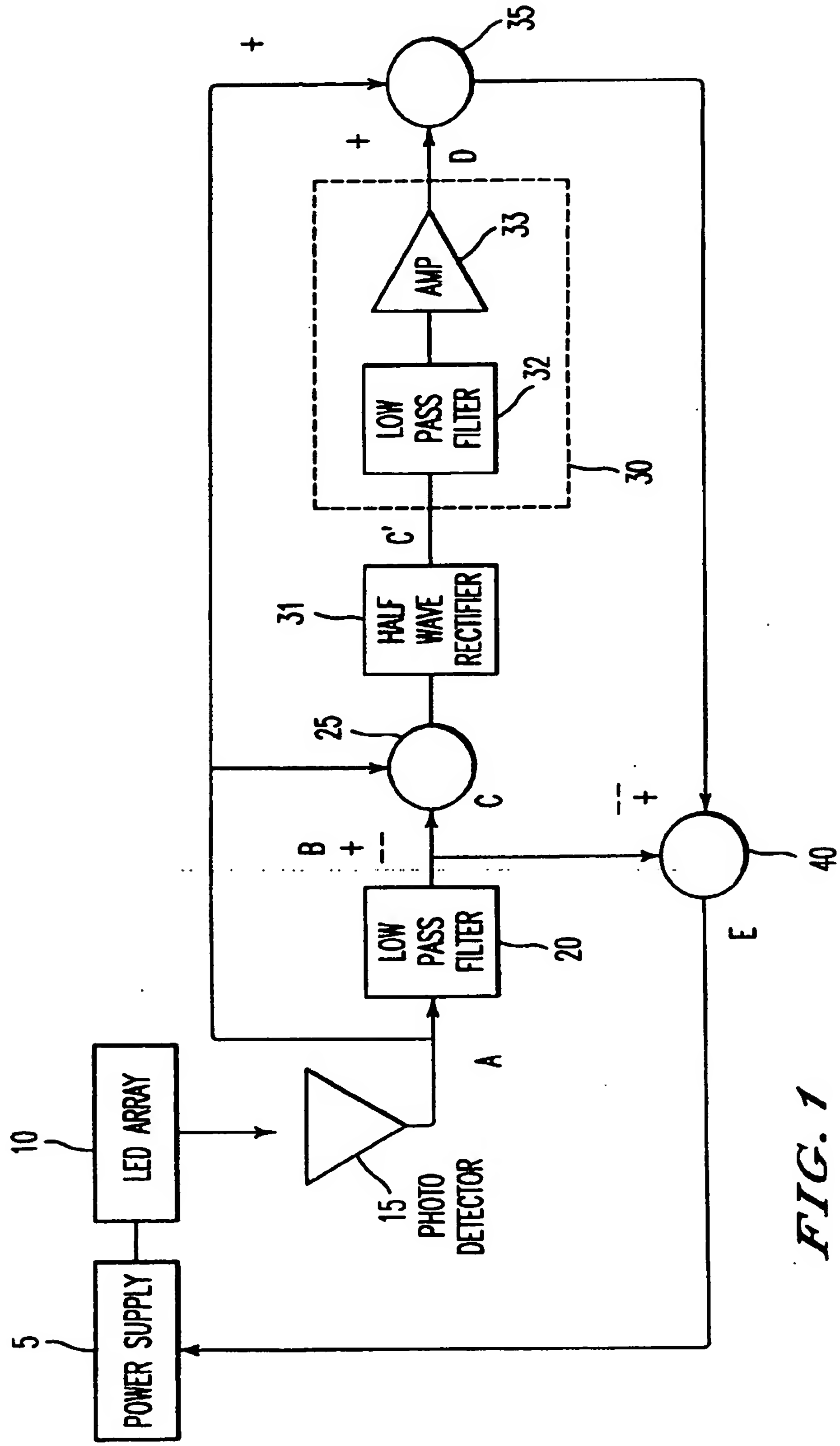
[57] **ABSTRACT**

An LED indicator system with at least one LED, and driving circuitry for driving the at least one LED. A power supply supplies a drive current to the at least one LED. A photo-detector detects a luminous output of the at least one LED and correspondingly outputs a detection signal. A conditioning circuit removes signal components indicative of stray light from at least one source other than the at least one LED, for example from sunlight reflected off of an LED array including the at least one LED, from the detection signal. As a result, the conditioning circuit generates a synthesized intensity feedback signal to provide to the power supply. The LED indicator system and driving circuitry for the at least one LED may further include a controller which compares the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal. A transmitter may transmit a signal indicating a result of the comparison executed by the controller.

19 Claims, 4 Drawing Sheets




POWER SUPPLY
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LED ARRAY
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15
PHOTO DETECTOR
A
LOW PASS FILTER
20
B
C
25
HALF WAVE RECTIFIER
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C'
LOW PASS FILTER
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AMP
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D
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FIG. 1

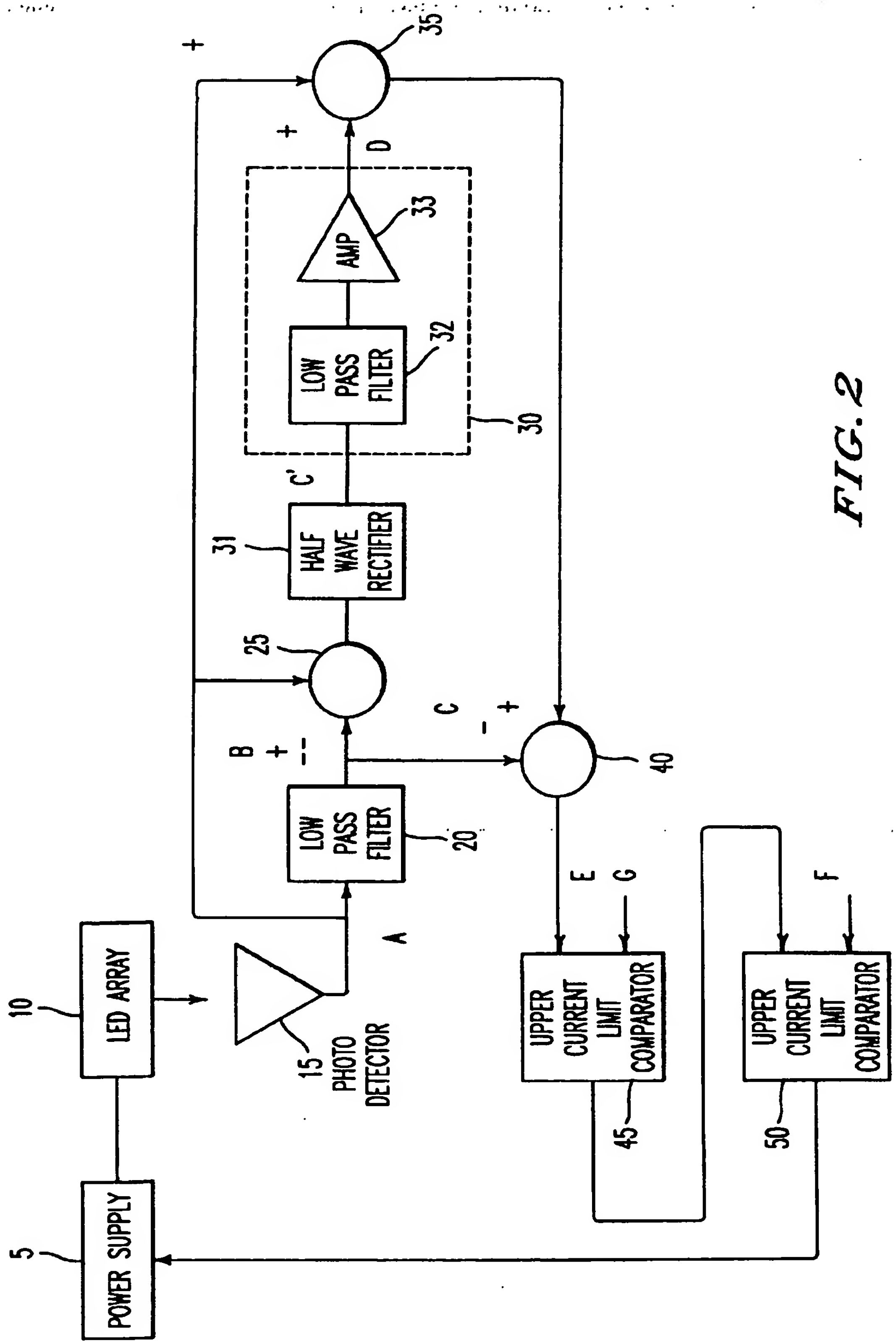
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FIG. 2

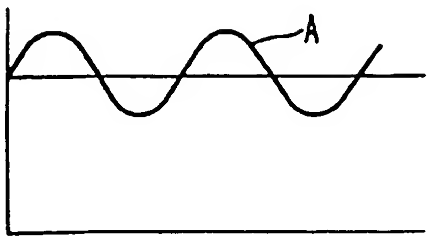


FIG. 3A

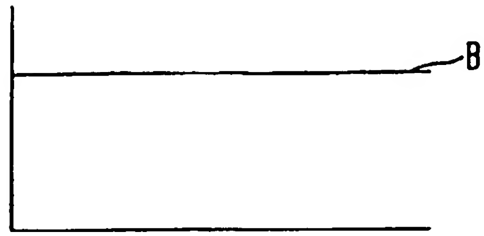


FIG. 3B

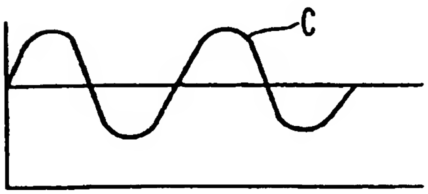


FIG. 3C

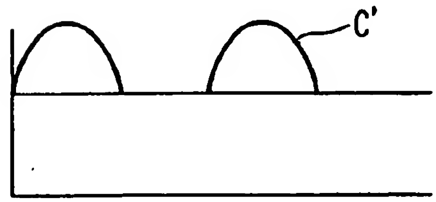


FIG. 3C'

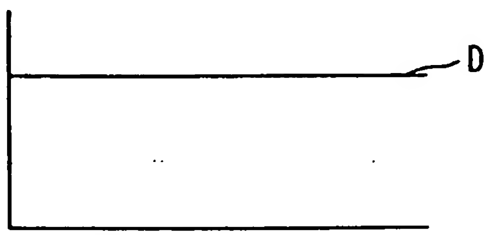


FIG. 3D

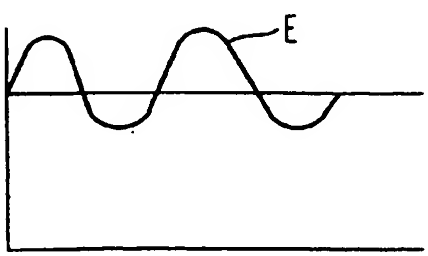


FIG. 3E

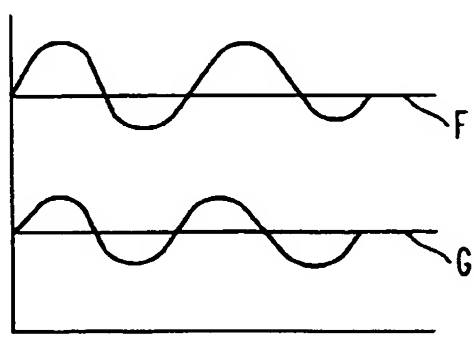
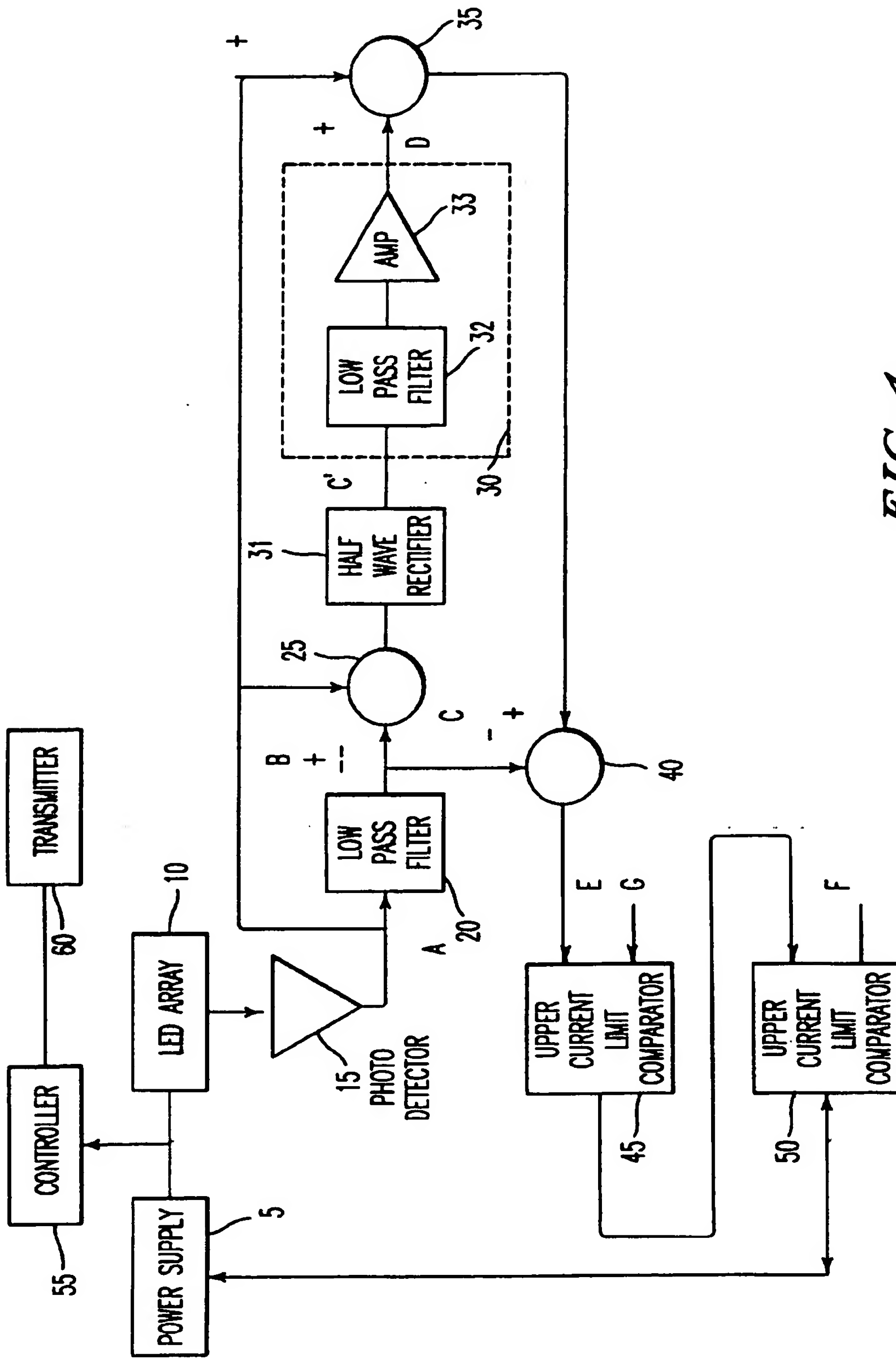


FIG. 3F



TRANSMITTER
60
CONTROLLER
55
LED ARRAY
10
POWER SUPPLY
5
15
PHOTO DETECTOR
LOW PASS FILTER
20
A
B
C
25
HALF WAVE RECTIFIER
31
C'
LOW PASS FILTER
32
AMP
33
30
D
35
40
E
G
F
UPPER CURRENT LIMIT COMPARATOR
45
UPPER CURRENT LIMIT COMPARATOR
50

FIG. 4

LED DRIVING CIRCUITRY WITH LIGHT INTENSITY FEEDBACK TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to an LED indicator and a driving circuit to drive an LED. More particularly, the present invention is directed to an LED indicator and a driving circuit that can drive an LED with a compensation for a loss in the luminous output of the LED. This invention can find particular application when the LED is utilized in a device such as a traffic signal or another indicating signal.

2. Discussion of the Background

The use of LEDs in indicating devices, such as traffic signals, is known. One drawback with using LEDs in an indicator such as a traffic signal is that luminous output of an LED degrades with both time and increasing temperature. For red LEDs degradation with respect to temperature will typically result in a loss of approximately one percent of intensity of the LED with every one degree Celsius increase in temperature. Conversely, as temperature decreases, intensity of light output from an LED increases. Moreover, LEDs gradually degrade over time, and thus become dimmer as they get older.

Known systems sense temperature at the LED or sense light output at the LED. and utilize the sensed temperature or sensed light output as a feedback to a power supply. Such a system is disclosed in U.S. Pat. No. 5,783,909 to Hochstein. This patent discloses (1) sensing temperature at an LED or sensing intensity output from an LED, (2) feeding back a signal proportional to the sensed temperature or intensity to a power supply, and (3) then increasing or decreasing the average current output by the power supply based on an increase or decrease in temperature in the light output of the LED.

In such a known system, sensing a luminous output of an LED may provide a benefit over sensing a temperature at the LED. Specifically, sensing luminous output of an LED allows compensation for both temperature-induced and age-induced degradation of the luminous output by the LED.

However, providing a photosensor to accurately detect the luminous output of an LED is somewhat problematic.

More particularly, to accurately detect the luminous output of an LED all other external stray light sources, e.g. sunlight, must be disregarded. That is, to provide an accurate feedback signal of a luminous output of an LED a photodetector must only detect the luminous output of the LED and cannot be affected by other forms of stray light, such as sunlight.

A second requirement of a photosensor is that it must gather light from a large enough sample of LEDs to be representative of all the LEDs in the lamp.

OBJECTS OF THE INVENTION

Accordingly, one object of the present invention is to provide an LED device with novel drive circuitry for an LED which can provide an accurate feedback signal of a luminous output of the LED.

A further more specific object of the present invention is to provide a novel drive circuit for an LED in which a feedback signal indicative of the luminous output of an LED is appropriately conditioned to eliminate the effect from external light sources, such as sunlight, so that the feedback signal provides an accurate representation of the luminous output of the LED.

A further more specific object of the present invention is to ensure that the appropriately compensated feedback signal is of a proper form for a power supply supplying power to an LED.

A further more specific object of the present invention is to utilize information from the novel drive circuitry to provide an indication of any improper operating conditions of the LED device or drive circuitry.

SUMMARY OF THE INVENTION

The present invention achieves these and other objects by providing a novel LED indicator with at least one LED, and novel driving circuitry for driving the at least one LED. In the present invention a power supply supplies current to the at least one LED. A photodetector detects a luminous output of the at least one LED and correspondingly outputs a detection signal. A conditioning circuit removes signals generated from stray light, for example from sunlight reflected off of an LED array including the at least one LED, from the detection signal. As a result, the conditioning circuit generates an intensity feedback signal to provide to the power supply.

As a further feature in the present invention, the novel LED indicator and novel driving circuitry for the at least one LED may further include a controller which compares the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal. As a further feature in the present invention, a transmitter may transmit a signal indicating a result of the comparison executed by the controller.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 shows one implementation of an LED indicator device and driving circuit according to the present invention;

FIG. 2 shows a modification of the LED indicator device and driving circuit of FIG. 1;

FIGS. 3A–3F show waveforms of signals generated in the LED indicator device and driving circuit of FIGS. 1 and 2; and

FIG. 4 shows a further modification of the LED indicator device and driving circuit of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures, wherein like reference numerals designate identical or corresponding parts throughout the several views, a pictorial example of an LED indicator device and LED driving circuit of the present invention is disclosed.

The present invention is directed to an LED indicator device and a driving circuit for an LED which can provide a feedback of an luminous output of the LED to control the drive current provided to the LED.

As shown in FIG. 1, in the present invention a power supply 5 provides power to illuminate an LED array 10. One typical form of the power supply 5 is a switching power supply which can employ power factor correction, current or voltage regulation, etc. The power supply 5 may specifically take the form of a flyback converter with power factor

correction incorporated in a commercially available IC, such as the Unitrode UC2852N. The LED array 10 may be a series or series-parallel arrangement of LEDs, and could also merely be a single LED. The present invention may find particular application as an LED traffic signal. In the context of LED traffic signals, the LED array 10 will typically be formed of parallel strings of series connected LEDs. A parallel connection of such LEDs provides redundancy in the event that one string of LEDs becomes inoperative. In a preferred embodiment the power supply 5 is a flyback current regulator based on the Unitrode UC2852N chip which drives the LED array 10 with a DC current and a fairly large sinusoidal current ripple of twice the line frequency. This ripple is characteristic of flyback-circuit power supplies and is a necessary element. Since the average value of the sinusoidal ripple is zero, the average total current is equal to that of the DC component alone.

A photodetector 15 is at an appropriate distance from the LED array 10 to allow it to collect light from a substantial number of LEDs within the LED array to measure the luminous output of the LED array 10. In the context of an LED array traffic signal, the photodetector 15 may be positioned behind the lens facing the LED array 10. The photodetector 15 provides a feedback signal to the power supply 5 so that the power supply 5 can control the current provided to the LED array 10.

As noted above, the luminous output of an LED may vary with both temperature and age, and particularly may degrade with increased temperature and with increased age. To compensate for such degradation, a current supplied to the LED can be increased with increasing temperature and age. Specifically, as a temperature at an LED increases the luminous output of the LED decreases. The photodetector 15 in this instance detects the decrease in luminous output of the LED array 10 and provides a feedback signal to the power supply 5 which controls the power supply 5 to increase the current supplied to the LED array 10. Thereby, the LED array 10 becomes brighter to compensate for any temperature-induced loss of luminosity. Similarly, as LEDs age they become dimmer, and the photodetector 15 can detect any age-induced diminution of the LED array 10. In this situation the photodetector 15 again provides a feedback signal to the power supply 5 to increase the current supplied to the LED array 10, so that the LED array 10 becomes brighter, to thereby compensate for the age-induced diminution of the LED array 10.

In these situations it is important for the photodetector 15 to provide an accurate indication of the luminous output of the LED array 10. This may be particularly problematic in LED array traffic signals since LED traffic signals are designed to have their LED arrays exposed outwardly by a lens, and are designed to be placed outdoors, where there is significant influence from external light sources.

Particularly, sunlight streaming in through a front lens of an LED traffic signal may be focused by the lens and projected onto the LED array 10. A portion of such sunlight may be reflected off the surface of the LED array 10 and onto the photodetector 15. Such reflected sunlight contributes to the output signal of the photodetector 15. The result of this is that the photodetector 15 does not provide an accurate indication of the luminous output of the LED array 10. The present invention has as one object to address such a situation.

To address this situation, the driving circuitry of the present invention includes conditioning circuitry between the photodetector 15 and the power supply 5 to ensure that

the light detected by the photodetector 15 is not influenced by external light sources in general, and particularly reflected sunlight from the LED array 10, other than the light output from the LED array 10.

Without this conditioning circuitry, the effect of sunlight reflecting off the LED array 10 is manifested as a DC component in the signal output from the photodetector 15. The present invention includes circuitry to reject this influence from such reflected sunlight by utilizing only the sinusoidal photodetector signal produced by the light originating from the LED array 10. That is, in the present invention, DC and low frequency components caused by stray light sources such as reflected sunlight and detected by the photodetector 15 are rejected.

However, to maintain stable operation of the power supply 5 when the power supply is implemented as a flyback current regulator using a power factor correction IC, it may be necessary for the intensity feedback signal to contain a DC component and a sinusoidal component in phase with the LED current waveform.

To achieve the above-noted operations, the present invention operates as follows.

The signal detected by the photodetector 15 is a signal such as is shown as signal A in FIG. 3A. This signal A contains both the sinusoidal and DC components indicative of the LED intensity and a DC component resulting from external light sources such as reflected sunlight. The output of the photodetector 15, i.e. signal A, is then passed through a low pass filter 20, which may have a cutoff frequency in the 10 Hz range, to separate the DC component. The signal output of the low pass filter 20 is signal B shown in FIG. 3B. Signal B thus represents the DC output of photodetector 15 contributed by both LED lighting and by sunlight reflecting off the LED array 10.

Next, by subtracting the DC component output from the photodetector 15, i.e. signal B, from the original signal output from photodetector 15, i.e. signal A, in difference circuit 25 the sinusoidal AC waveform C is produced. Signal C is then half-wave rectified by rectifier 31 and smoothed and amplified through a smoothing and amplifying circuit 30. This smoothing and amplifying circuit 30 can include a low-pass filter 32 and an amplifier 33. A waveform of the signal C after being passed through the half-wave rectifier 31 is shown in FIG. 3C'. The signal C' is then low-pass filtered and amplified as necessary to produce the DC signal D output of the smoothing circuit 30 shown in FIG. 3D. The amplitude of this DC signal D is controlled by the amplifier 33 to be proportional to the amplitude of the sinusoidal component of the original waveform signal A.

Next, the present invention synthesizes a feedback signal containing both amplitude and phase information to provide to the power supply 5. This synthesized feedback signal is free of signals attributable from the reflected sunlight and other low frequency light sources.

To achieve this operation, the original signal output of the photodetector 15, i.e. signal A, containing a sinusoidal component indicative of LED intensity and DC components indicative of light from LED array 10 and of stray light is summed in adder 35 with signal D. a DC output indicative of LED intensity. The output of the adder 35 is then the original signal plus a DC signal indicative of LED intensity. This output is then provided to a difference circuit 40. In the difference circuit 40 the signal B output from the low pass filter 20, which has a DC level with an amplitude proportional to the amplitude of the DC component of the photodetector 15, is subtracted from the signal output of adder 35,

to thereby create a composite signal E, i.e. E=(A+D)−B. That is, the resulting signal contains only the AC and DC signals indicative of LED intensity. This composite signal E serves as a feedback signal required by the power supply 5 to maintain a desired current in the LED array 10. More particularly, this composite signal E contains amplitude and phase information needed to maintain a stable operation of a current regulator circuit in the power supply 5.

With the above-discussed operation in the present invention, the composite signal E is free of DC components indicative of stray light sensed by the photodetector. Moreover, the composite signal E also contains an appropriate DC component in phase with the sinusoidal signal, as is required by the power supply S when the power supply 5 is implemented as a flyback current regulator. Therefore, in the present invention an accurate intensity feedback signal can be provided to the power supply 5 to control the illumination of the LED array 10.

One problem which may arise in the device of FIG. 1 is that an excessively high current or an excessively low current may be output from the power supply 5 based on the composite feedback signal E. That is, if the LED array 10 is of inadequate intensity, the composite signal E may be a low value, which may result in the power supply 5 providing too much current to the LED array 10. Conversely, if the LED array 10 exceeds intensity limits, the composite signal E may be at too high a value, and too little current may then be supplied from the power supply 5 to the LED array 10. Providing too little current to the LED array 10 may reduce the current drawn by the signal power supply to a level insufficient to properly operate the load switch controlling the LED traffic signal. Reliable operation of the LED array 10 may become unpredictable with respect to light output if too little current is supplied to the LED array 10. When the present invention is implemented as an LED traffic signal, Triac-based load switches are often used to control traffic signals. Such Triac-based load switches may become unreliable when switching low currents, and this can result in traffic signal operational problems.

To address these concerns, a modification of the embodiment of FIG. 1 is shown in FIG. 2. This embodiment of FIG. 2 is identical to the embodiment of FIG. 1 except the embodiment of FIG. 2 includes an upper current limit comparator 45 and a lower current limit comparator 50. To achieve the upper and lower current limiting operations, in the present invention as shown in FIG. 2 the composite feedback signal E is fed to the upper current limit comparator 45. The upper current limit operation is begun by establishing a current signal G with a level equal to approximately half that of the intensity feedback signal E under normal operating conditions and 25° Celsius. This signal G is compared with the composite intensity feedback signal E such that when the level of signal G exceeds the level of the intensity feedback signal E, the signal G replaces the signal E as a feedback to the power supply 5. This ensures that a signal of a minimum value of signal G is always supplied to the power supply 5, and that accordingly an excessive current is not output from the power supply 5 to the LED array 10.

A simple method of implementing the upper current limit comparator 45 is to apply both signals E and G through a pair of wire-ORed diodes with cathodes connected to ground through a common resistor. In this configuration the larger of the two signals appears across the resistor and the other signal is blocked by its reversed-biased diode. Such a structure essentially forms an analog comparative circuit where only the larger of two analog input signals appears at the output.

The lower current limit operation is achieved by applying the output of the upper limit comparator 45 to the lower current limit comparator 50, and comparing it with a current signal F. Signal F is greater in amplitude than the intensity feedback signal E under normal conditions. In this situation, the higher amplitude LED current signal F is compared to the intensity feedback signal E, and the signal F replaces the intensity signal E to the power supply if the intensity feedback signal is greater than the signal F. This ensures that a signal with the maximum value of signal F is supplied to the power supply 5, and that accordingly a minimum current is always provided from the power supply 5 to the LED array 10.

A simple method of implementing the lower current limit comparator 50 is to apply signals E and F through a pair of wire-ANDed diodes with anodes connected to a positive supply voltage through a common resistor. In this configuration, the smaller of the two signals appears at the anode connections of the two diodes while the other signal is blocked by its reversed-biased diode. This circuit again forms a type of analog comparative circuit. This time, however, only the smaller of the two analog input signals appears at the output.

A further feature of the present invention is that the use of the intensity feedback allows the incorporation of additional features which are not otherwise possible in LED indicator devices, such as LED traffic signals. With the intensity feedback operation in the present invention, and a further modification of the present invention as shown in FIG. 4, a controller 55 is provided to monitor the signal from the power supply 5 to the LED array 10 indicating the current output to the LED array 10, and to receive the intensity feedback signal indicating the actual intensity of the LED array 10. By evaluating these signals, a condition of inadequate or excessive intensity of the LED array 10 may be determined when the difference between the signal output from the power supply and the intensity feedback signal exceeds a predetermined threshold. This condition may arise from long-term degradation of the LEDs, or such a condition could be a transitory condition resulting from a temporarily high temperature at the LED array 10. In either case, when such a condition arises a traffic controller circuitry or maintenance personnel can be alerted of such a condition.

In this situation, connected to the controller 55 may be a transmitter 60 which can repeatedly transmit information as to the operation of the driving circuitry of FIGS. 1 and 2. FIG. 4 shows implementation of the controller 55 and transmitter 60 in the circuitry of FIG. 2, however the circuitry of FIG. 1 can also utilize the controller 55 and transmitter 60. The transmitter 60 may be a simple infrared transmitter which sends one code to indicate a normal operation of the LED device, and which transmits a second code, or alternatively no code, to indicate that the LED device is functioning improperly, i.e., that the difference between the signal output from the power supply 5 to the LED array 10 and the intensity feedback signal exceeds a predetermined threshold. This second code could also be sent when the upper current limit comparator 45 is engaged.

It is also clearly possible to have additional codes indicating various degrees of non-compliance with any intensity requirements.

Maintenance personnel could then be provided with receivers, for example hand-held infrared receivers, which they could point at a traffic signal including the transmitter 60 to read the codes being transmitted. The received codes could then be decoded to provide an indication of the operation of the LED traffic signal.

Still another approach to transmitting such information could employ power line communication in the transmitter 60. In this situation, a microprocessor in a central controller (not shown) could periodically poll a series of traffic signals by sending appropriate codes over the power lines. When a traffic signal circuit receives its identification code from controller 55, it can respond by transmitting via the same power line, through transmitter 60, its current status with a system using the first and second codes as noted above. In one embodiment, the central controller may record in its memory instances when specific traffic signals are not meeting requirements. Alternatively, the transmitter 60 may be equipped with a modem or radio link allowing the intensity information to be downloaded immediately to a main traffic control center.

Obviously, numerous additional modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

What is claimed is:

1. An LED indicator system, comprising:

(a) at least one LED;

(b) a power supply to supply current to the at least one LED based on a received synthesized intensity feedback signal;

(c) a photodetector to detect a luminous output of the at least one LED, and to correspondingly output a detection signal;

(d) a compensation circuit to remove components of stray light from at least one source other than said at least one LED from the detection signal to generate the synthesized intensity feedback signal provided to the power supply.

2. The LED indicator system according to claim 1, wherein said detection signal includes a sinusoidal component and a DC component from the at least one source, and wherein said conditioning circuit comprises:

i) a low pass filter to extract a first substantially DC signal proportional to a DC component in the detection signal; and

ii) a difference circuit to subtract the first substantially DC signal from the detection signal to generate a sinusoidal AC waveform.

3. The LED indicator system according to claim 2, wherein said conditioning circuit further comprises:

iii) a smoothing and amplifying circuit to smooth and amplify the sinusoidal AC waveform to generate a second substantially DC signal proportional to a level of the sinusoidal AC component in the detection signal.

4. The LED indicator system according to claim 3, wherein said conditioning circuit further comprises:

iv) an adder circuit to add the second substantially DC signal and the detection signal, to generate an intermediate composite signal; and

v) a second difference circuit to subtract the first substantially DC signal from the intermediate composite signal and to generate the synthesized intensity feedback signal.

5. The LED indicator system according to claim 4, wherein said conditioning circuit further comprises:

vi) an upper current limit comparator to ensure that the synthesized intensity feedback signal has a minimum value; and

vii) a lower current limit comparator to ensure that the synthesized intensity feedback signal does not exceed a maximum value.

6. The LED indicator system according to claim 1, further comprising:

(e) a controller to compare the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal.

7. The LED indicator system according to claim 6, further comprising:

(f) a transmitter to transmit a signal indicating a result of the comparison executed by the controller.

8. The LED indicator system according to claim 5, further comprising:

(e) a controller to compare the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal.

9. The LED indicator system according to claim 8, further comprising:

(f) a transmitter to transmit a signal indicating a result of the comparison executed by the controller.

10. A driving circuit for at least one LED, comprising:

(a) a power supply to supply current to the at least one LED based on a received synthesized intensity feedback signal;

(b) a photodetector to detect a luminous output of the at least one LED, and to correspondingly output a detection signal;

(c) a compensation circuit to remove components of stray light from at least one source other than said at least one LED from the detection signal to generate the synthesized intensity feedback signal provided to the power supply.

11. The driving circuit according to claim 10, wherein said detection signal has a sinusoidal AC component and a DC component from the at least one source, and wherein said conditioning circuit comprises:

i) a low pass filter to filter the detection signal to generate a first substantially DC signal proportional to a DC component in the detection signal; and

ii) a difference circuit to subtract the first substantially DC signal from the detection signal to generate a sinusoidal AC waveform.

12. The driving circuit according to claim 11, wherein said conditioning circuit further comprises:

iii) a smoothing and amplifying circuit to smooth and amplify the sinusoidal AC waveform to generate a second substantially DC signal proportional to a level of the sinusoidal AC component in the detection signal.

13. The driving circuit according to claim 12, wherein said conditioning circuit further comprises:

iv) an adder circuit to add the second substantially DC signal to the detection signal, to generate an intermediate composite signal; and

v) a second difference circuit to subtract the first substantially DC signal from the intermediate composite signal to generate the synthesized intensity feedback signal.

14. The driving circuit according to claim 13, wherein said conditioning circuit further comprises:

vi) an upper current limit comparator to ensure that the synthesized intensity feedback signal has a minimum value; and

vii) a lower current limit comparator to ensure that the synthesized intensity feedback signal does not exceed a maximum value.

15. The driving circuit according to claim 10, further comprising:

(d) a controller to compare the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal.

16. The driving circuit according to claim 15, further comprising:

(e) a transmitter to transmit a signal indicating a result of the comparison executed by the controller.

17. The driving circuit according to claim 14, further comprising:

(e) a controller to compare the current supplied by the power supply to the at least one LED with the synthesized intensity feedback signal.

18. The driving circuit according to claim 17, further comprising:

(f) a transmitter to transmit a signal indicating a result of the comparison executed by the controller.

19. An LED indicator system, comprising:

(a) at least one LED;

(b) a power supply to supply current to the at least one LED based on a received synthesized intensity feedback signal;

(c) a photodetector to detect a luminous output of the at least one LED, and to correspondingly output a detection signal;

(d) means for removing components of stray light from at least one source other than said at least one LED from the detection signal to generate the synthesized intensity feedback signal provided to the power supply.

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United States Patent [19]

Grossman et al.

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[45] Date of Patent: Oct. 3, 2000

[54] **LED DRIVING CIRCUITRY WITH VARIABLE LOAD TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED**

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[73] Assignee: **Dialight Corporation**, Manasquan, N.J.

[21] Appl. No.: 09/144,097

[22] Filed: Aug. 31, 1998

[51] Int. Cl.^{7} G05F 1/00

[52] U.S. Cl. 315/159; 315/112; 315/117; 315/158; 315/307

[58] Field of Search 315/50, 112, 117, 315/118, 224, 225, 291, 307, 151, 159, 158; 363/89, 80

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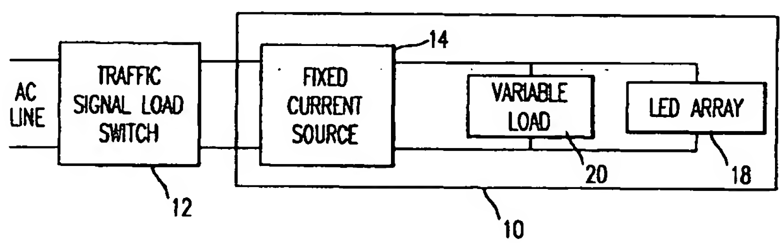
Attorney, Agent, or Firm—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

[57] **ABSTRACT**

Circuitry for driving an LED array and a lamp including such circuitry. A fixed current source outputs a fixed current to an LED array. A variable load is provided in parallel to the LED array to also receive an output from the fixed current power supply. The variable load senses a condition affecting a luminous output of the LED array and varies an impedance based on this sensed condition. This variable load may typically include a thermistor or a photodetector. As the impedance of the variable load changes, current diverted from the LED to the variable load changes. Thereby, current supplied to the LED array, and thereby the intensity LED, can be controlled based on the impedance changing element in the variable load.

10 Claims, 1 Drawing Sheet



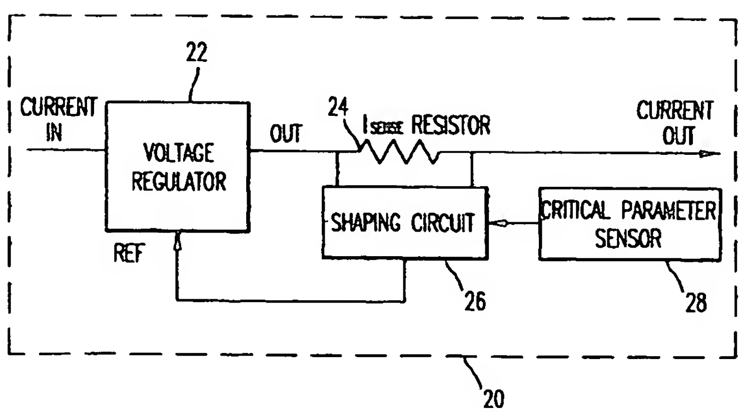


FIG. 1

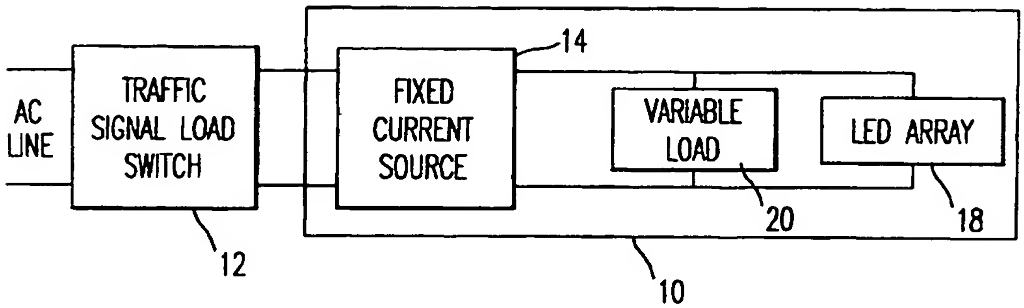
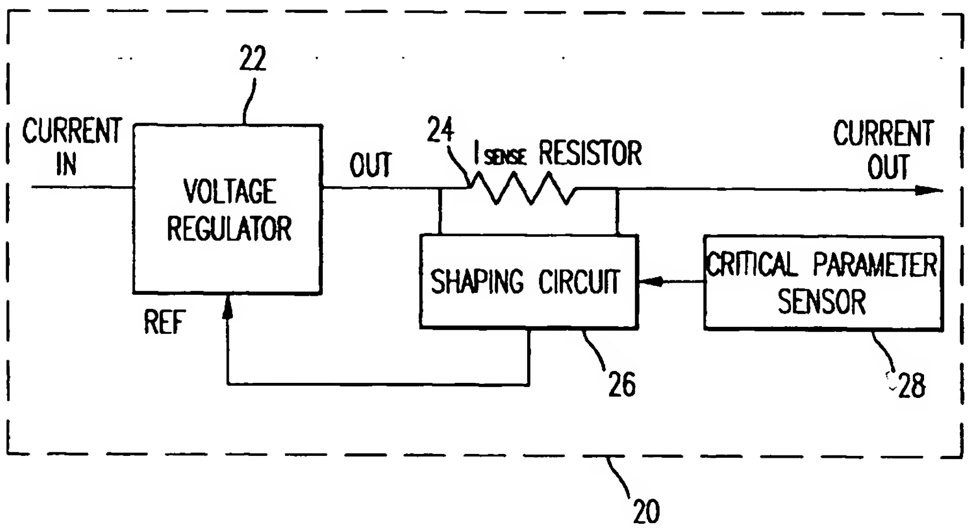

AC
LINE
TRAFFIC
SIGNAL LOAD
SWITCH
FIXED
CURRENT
SOURCE
14
VARIABLE
LOAD
LED ARRAY
20
18
12
10

FIG. 2


22
CURRENT
IN
VOLTAGE
REGULATOR
OUT
24
I SENSE RESISTOR
CURRENT
OUT
SHAPING CIRCUIT
CRITICAL PARAMETER
SENSOR
REF
26
28
20

LED DRIVING CIRCUITRY WITH VARIABLE LOAD TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to an LED lamp and a driving circuit to drive an LED array. More particularly, the present invention is directed to an LED lamp and a driving circuit which can drive an LED array with a compensation for conditions which change luminous output of the LED array. This invention can find particular application where the LED array is utilized in a device such as a traffic signal or another indicating signal.

2. Discussion of the Background

The use of LED arrays in indicating devices, such as traffic signals, is known. One drawback with using LEDs in an indicator such as a traffic signal is that luminous output of an LED degrades with both time and increasing temperature. For red LEDs degradation with respect to temperature will typically result in a loss of approximately one percent of intensity of the LED with every one degree centigrade increase in temperature. Conversely, as temperature decreases, intensity of light output by an LED increases. Moreover, LEDs gradually degrade over time, and thus become dimmer as they get older.

One known system senses a temperature at the LED or senses a light output at the LED, and utilizes the sensed temperature or sensed light output as a feedback to a power supply. Such a system is disclosed in U.S. Pat. No. 5,783,909 to Hochstein. This patent discloses (1) sensing either temperature at an LED or intensity output of an LED, (2) feeding back the sensed temperature or intensity to a power supply, and (3) then increasing or decreasing an average current output by the power supply based on any increase or decrease in temperature at the LED or any increase or decrease in the light output of the LED.

One drawback with such a system as disclosed in Hochstein is that such a system may not operate properly at low temperatures. As a specific example, a traffic signal is normally switched on and off by solid state relays. These relays may have a minimum current below which the relays cannot operate reliably. Utilizing a feedback operation such as in the device of Hochstein results in the following problems during low temperature operation of the LED array.

Because of the feedback operation in the device of Hochstein, at a low temperature a small total current is supplied to drive an LED array since the LED array is very bright at the low temperature. The total current supplied to the LED array may as a result cause the current through the load switch to fall below the minimum current required for the solid state relays to properly operate. In traffic signals it is also desirable to reduce lamp intensities at low temperatures while maintaining an input current to be compatible with a lamp controller. The device of Hochstein does not address problems of controller compatability.

OBJECTS OF THE INVENTION

Accordingly, one object of the present invention is to provide novel drive circuitry for an LED array which can overcome the drawbacks in the background art.

A further and more specific object of the present invention is to provide a novel drive circuit for an LED array in which the current supplied to the LED array can be compensated for without the use of a feedback circuit.

SUMMARY OF THE INVENTION

In one embodiment the present invention achieves these objects by forming a variable load in parallel to an LED array to be driven. This variable load has the property that the current drawn by the variable load varies based on a sensed parameter—for example, based on the sensed temperature at the LED array or the sensed intensity of light output by the LED array. This variation in current absorbed by the variable load changes the amount of current provided to the LED array, to thereby control the luminous output of the LED array.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing, wherein:

FIG. 1 shows one implementation of an LED lamp and driving circuit according to the present invention; and

FIG. 2 shows a detailed description of a variable load of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures, wherein like reference numerals designate identical or corresponding parts throughout the several views, a pictorial example of the LED lamp and LED driving circuitry of the present invention is disclosed.

FIG. 1 shows an LED lamp 10 of the present invention connected to a traffic signal load switch 12, which in turn is connected to an AC power line. This disclosed embodiment in the present invention is directed to the LED lamp 10 being utilized in an LED traffic signal or similar LED indication signal. The LED lamp 10 includes a fixed current source 14 supplying power to both a variable load 20 and an LED array 18.

The fixed current source 14 can take the form of outputting either pulses or a direct current. If the fixed current source 14 outputs pulses, these pulses will be of a fixed amplitude and frequency. If the fixed current source 14 outputs a direct current, the direct current will be constant.

The fixed current source 14 is connected to the traffic signal load switch 12. The traffic signal load switch 12 provides power to one or more LED indication signals—i.e., to one or more LED lamps 10. The AC voltage from the AC line is thereby delivered through the traffic signal load switch 12 to the fixed current source 14 of the LED lamp 10.

The variable load 20 and the LED array 18 are arranged in parallel, and thereby any current absorbed by the variable load 20 is diverted from the LED array 18. Consequently, by varying the impedance of the variable load 20, the current passing through the LED array 18 is varied, and as a result the intensity of light output by the LED array 18 is varied.

This variable load 20 includes at least one element which senses a condition which affects the output light intensity of the LED array 18. For example, this variable load 20 can include either a thermistor circuit or a photodetector, provided that the thermistor or photodetector is configured to provide a variable impedance load. In one embodiment, this variable load 20 includes a thermistor circuit which has a variable impedance based on temperature. As a temperature increases, the resistance of the thermistor decreases, and this

results in an increase in the impedance of the variable load 20, as discussed in further detail below. As a result, more current is diverted to the LED array 18. Thus, as the temperature at LED array 18 increases, the current supplied to the LED array 18 increases to maintain the luminous intensity of the LED array 18. A similar operation can be affected if the variable load 20 includes a photodetector as a variable impedance element which monitors light output by the LED array 18.

The above-identified operations can be summarized as follows. As temperature at LED array 18 increases or light output by LED array 18 decreases, the impedance of the variable load 20 increases. Thereby, more current from the fixed current source 14 is diverted to the LED array 18 so that the current passing through the LED array 18 increases, and as a result the illuminance of the LED array 18 increases. Thereby, any loss of illumination in the LED array 18 which results from an increase in temperature is compensated for. When a photodiode is used in the critical parameter sensor 28, any loss of intensity due to aging of the LED array 18 is compensated for as well.

FIG. 2 shows a detailed explanation of the structure of the variable load 20.

As shown in FIG. 2, the variable load 20 includes a voltage regulator 22. The voltage regulator 22 may typically be a 3-terminal voltage regulator—for example model number LM 317 manufactured by National Semiconductor among others, or an equivalent voltage regulator. An output from the fixed current source 14 is supplied to the voltage regulator 22 as the "current in", and it is also supplied to the LED array 18 as shown in FIG. 1. The variable load 20 also includes a sense resistor 24 at an output of the voltage regulator 22. Formed across the sense resistor 24 is a shaping circuit 26. A critical parameter sensor 28 provides an input to the shaping circuit 26. The critical parameter sensor 28 can be a thermistor or a photodetector with variable impedance as discussed above. The output of the shaping circuit 26 is then fed back to the voltage regulator 22.

The elements forming the shaping circuit 26 are used to model characteristics of the critical parameter sensor 28 as discussed further below. The voltage regulator 22 is configured in this embodiment to form a linear current regulator. It is well known that a linear current regulator can be made from a commonly available 3-terminal voltage regulator 22 such as noted above. Such a voltage regulator forms a linear current regulator by placing the low value current sense resistor 24 in series with the output of the voltage regulator 22 and feeding back a voltage developed across the sense resistor 24 to a reference terminal REF of the voltage regulator 22. In the embodiment shown in FIG. 2 the shaping circuit 26 is used to moderate this feedback. The shaping circuit 26 is formed of active and passive circuitry as necessary to vary the signal presented to the REF terminal of the voltage regulator 22. As the voltage generated or impedance of the critical parameter sensor 28 changes, the reference voltage applied to the REF terminal of the voltage regulator 22 will vary.

The actual active and passive components forming shaping circuit 26 will vary based on the other components in LED lamp 10 and desired characteristics for LED lamp 10. However, the shaping circuit 26 should perform certain functions. First, the shaping circuit 26 should be constructed to compensate for the non-linear response of the LED array 18 to temperature and any non-linear properties of a thermistor or photodetector as the critical parameter sensor 28. As noted above, an LED may have a response to temperature of losing approximately 1% of light output per degree centigrade, which is a non-linear response, and a thermistor has a similar non-linear response. The shaping circuit 26 should select the active and passive components therein to address this non-linear quality of the LED array 18 and the critical parameter sensor 28.

Further, in the context of temperature compensation the shaping circuit 26 is constructed to provide a low stop to ensure that the variable load 20 always absorbs a certain current to ensure proper operation of the LED array 18. As noted above, if the current supplied to an LED falls below a certain level, the performance of the LED becomes unpredictable. This is a drawback in the background art which utilizes a feedback such that at low temperatures the current provided to an LED can drop to such a low level as to cause erratic illumination of the LED. Further, at low temperatures a current generated may be too low to switch the solid state on and off relays controlling a traffic signal. For this reason, the shaping circuit 26 should include a resistance in parallel with the critical parameter sensor 28 so that the reference voltage provided to the REF terminal of the voltage regulator 22 does not fall below a predetermined level. This ensures that the impedance of the variable load 20 does not drop too low and that the variable load 20 does not absorb too great a current at this low stop value.

In the circuit of FIG. 2, in the example that the critical parameter sensor 28 includes a thermistor, the operation is as follows. At a low temperature, the impedance of the thermistor of the critical parameter sensor 28 will be very high. However, as noted above the shaping circuit 26 includes a resistance in parallel with the thermistor of the critical parameter sensor 28 such that even if the critical parameter sensor 28 has an extremely high impedance, current still flows through the shaping circuit 26 to the REF terminal of the voltage regulator 22. This ensures that the voltage input to the reference terminal REF of the voltage regulator 22 still maintains a minimum value, so that the "current out" is not too high. This results in the variable load 20 maintaining an overall minimum impedance—i.e., the overall impedance of the variable circuit 20 does not fall below a predetermined level. This results in a minimum current always passing through the LED array 18. If the shaping circuit 26 is not appropriately configured with a low stop as discussed above, then the impedance of the variable load 20 may drop to too low a level. In that case, too much current will be diverted from the LED array 18. As noted above, if the LED array 18 does not receive an adequate driving current, illumination of the LED array becomes unpredictable.

Conversely, under very high temperature conditions the impedance of the thermistor in the critical parameter sensor 28 becomes very low. The voltage then input to the reference terminal REF of the voltage regulator 22 becomes very high, and as a result the "current out" is restricted. Thus, the variable load 20 in this high temperature operation takes on a very high impedance. This ensures that more current is diverted from the fixed current source 14 to the LED array 18 to increase the current passing through the LED array 18, to compensate for any temperature induced losses in intensity of light output by the LED array 18. No high stop structure is required in the present invention since even if the variable load 20 has an infinite resistance, this will only result in the LED array 18 receiving all of the current output from the fixed current source 14. The fixed current source 14 then should be selected to output a fixed current which if totally applied to the LED array 18 does not damage the LED array 18.

The above discussion has focused on an example in which the critical parameter sensor **28** is a thermistor. Similar operations as noted above also are effectuated if the critical parameter sensor **28** is a photosensor which has a variable impedance based on a detected light output.

If the critical parameter sensor **28** is a thermistor, this critical parameter sensor **28** should be placed closed enough to the LED array **18** to determine the temperature at the LED array **18**. If the critical parameter sensor **28** is a photodetector, this photodetector should be placed near the LED array **18** to receive an indication of light output by the LED array **18**. Further, if the critical parameter sensor **28** is a photodetector, the photodetector should be appropriately shielded from ambient light so that the photodetector only detects the intensity of light output by the LED array **18**.

Also, the present invention can be applied to any driving circuit for any number of LEDs and arrays of LED, and it is not limited to driving one LED array.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

We claim:

1. Apparatus for indicating signals comprising:
   (a) an LED array;
   (b) a fixed current source which, in use, outputs a fixed current; and
   (c) a variable load electrically connected in parallel to the LED array, said variable load including a parameter sensor which has a variable impedance based on a condition affecting luminous output of the LED array, said LED array and said variable load both receiving, in parallel electrically, said fixed current output of said fixed current source.

2. The driving circuit according to claim 1, wherein:
   (a) said the parameter sensor is a thermistor, and
   (b) the condition is the temperature at the LED array.

3. The driving circuit according to claim 1, wherein:
   (a) said parameter sensor is a photosensor, and
   (b) the condition is an intensity of light output of the LED array.

4. The driving circuit according to claim 1, wherein said variable load further includes a shaping circuit having a resistance in parallel to said parameter sensor.

5. The driving circuit according to claim 4, wherein said variable load further includes a voltage regulator which, in use, receives the fixed current from said fixed current source and receives an output of said shaping circuit as a feedback reference voltage.

6. Apparatus for indicating signals comprising:
   (a) an LED array;
   (b) means for supplying a fixed current; and
   (c) means for varying an impedance, including a parameter sensor, in parallel electrically to the LED array based on a condition affecting luminous output of the LED array, said LED array and said means for varying an impedance both receiving, in parallel electrically, said fixed current output of said means for supplying a fixed current.

7. The driving circuit according to claim 6, wherein:
   (a) said means for varying an impedance includes a thermistor, and
   (b) the condition is the temperature at the LED array.

8. The driving circuit according to claim 6, wherein:
   (a) said means for varying an impedance includes a photosensor, and
   (b) said condition is the intensity of light output of the LED array.

9. The driving circuit according to claim 6, wherein said means for varying an impedance includes a shaping circuit.

10. The driving circuit according to claim 9, wherein said means for varying an impedance further includes a voltage regulator which, in use, receives the fixed current from the means for supplying a fixed current and receives an output of said shaping circuit as a feedback reference voltage.

* * * * *